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QUALITY ASSURANCE FOR ELECTRON CYCLOTRON RESONANT HEATING (ECRH)

R. R. Lauze
P. G. Karsner
J. W. Heefner

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R. R. Lauze, P. G. Karsner, J. W. Heefner
Lawrence Livermore National Laboratory
P.O. Box 5511, L-532
Livermore, CA 94550

Abstract

Due to the complexity of the Tandem Mirror Experiment-Upgrade (TMX-U) and the importance of operating time, all the subsystems must be made as reliable as possible. ECRH is such a subsystem. In order to accomplish this task with ECRH, two things were needed:

(1) Training in proper operation and maintenance of the system;

(2) A Quality Control Assurance program.

This paper will explain how these things were implemented.

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Introduction

ECRH is a large, complex subsystem of the TMX-U machine. It requires vast and varied talents to maintain and operate daily. All of its short comings were not readily apparent or well defined. Problems began occurring with more than normal regularity and ECRH was becoming less than reliable. Many man hours of operating time were being lost due to equipment failures. Lost operating time meant an unnecessary expenditure of money and manpower. It was determined that a Quality Control and training program should be implemented.

Initially, the ECRH Quality Control system was set up to define problem areas and increase system reliability. As the system grew and took shape, it became apparent that it could be used to benefit the ECRH system in many ways.

The quality control and training system set up for ECRH consists of two major parts:

(1) Improve operation through training.

(2) Define problem areas and take corrective action.

Improved operation was accomplished by first developing a system description manual. The manual aided in training new technicians and reduced equipment down time. Secondly, a better understanding of the physics behind ECRH was gained by the technicians.

Defining problem areas was accomplished by developing a daily systems check list and a computerized systems failure log.

The daily systems check list helped make technicians more familiar and aware of the system. It has aided in pin-pointing potential system problems.

The failure log is a computer-based record keeping system. It was instituted to show system failure trends and weak spots.

Quality Control

Handbook and Checklist

The decision was made to embark on a training and quality control system. The first task was to divide the system into major sections. Several of these sections are: High-Voltage feedback, Magnets, Interlocks, Gyrotron theory, Control signal operation and monitoring. Technicians, Engineers, and Physists took a section or sections and began writing a theory of operation. Along with theory, schematics, and block diagrams had to be furnished.

Everyone, involved in the assembly of the description manual, learned more about the system. It was imperative that each person be absolutely familiar with the section they were writing. Each individual would be responsible for answering any questions about their section.

Once the manual was completed, everyone received a copy and read it at their own pace. This allowed them to learn the system a section at a time and without any pressure to do so. The section could be reviewed daily until the person was sure he had learned it thoroughly. All concerned felt that this method would have longer lasting effects.

The manual is an aid to troubleshooting and repairing the major portions of the ECRH system. When system failures occur, the manual can be readily transported to the problem area. It is used as a reference and guide to get the technician on the right track. This has reduced valuable down time. Approximately 30 percent less down time for repair has been noted. A copy of the book is on display.

Also studied were the effects of mode shifting, frequency of oscillation, and antenna aiming. All three of these parameters have an effect on how well the ECRH power couples into the TMX-U plasma. A system of checks had to be established to determine that these parameters were correct.

Upon studying the effects and causes of, mode shifting two major points became apparent:

(1) It most often occurs during ECRH pulses when the TMX-U Magnets were on.

(2) Mode shifting can break costly Gyrotron tube windows.

ECRH was conditioned before every physics data run without TMX-U Magnets. Because of this, there was no way to determine if mode shifting would occur when data shots were taken. To combat this problem, ECRH is now conditioned alone. When it is up to power, shots are taken with ECRH and TMX-U Magnets only. If mode shifting occurs, fine tuning is performed. This process delays the start of obtaining physics data but once started no physics data shots are wasted.

Mode shifting can cause Gyrotron tube windows to form circular mode rings and eventually crack. In order to save windows from breaking, they are checked if frequent mode shifting occurs. If the window shows signs of damage, it is changed.

We discovered that the ECRH Gyrotrons had been oscillating at two frequencies, 28 GHz and 26 GHz. 28 GHz is where optimum plasma coupling occurs. 26 GHz can occur with improper ECRH magnet settings. 26 GHz does not couple very well into the plasma and can cause damage to the Gyrotron tubes. This is combated by the use of bandpass filters that have a bandpass of 28 GHz ±500 KHz. The outputs of the filters are observed on oscilloscopes, and the Gyrotron is tuned until 28 GHz is obtained.

Antenna aiming is accomplished by placing heat sensitive paper inside the TMX-U vessel at the precise place that RF power is to be concentrated. High-power shots turn the heat sensitive paper dark at the places the RF power is concentrated. By observing the relationship of the dark areas to the center of the paper, the proper aiming can be determined. If improperly aimed, the antenna can be re-positioned and the process repeated until proper aiming is achieved.

QC Reporting

The second task embarked upon was a Quality Control reporting and logging method. This meant two things had to be formatted. The first was a daily system check list. The second was a system failure log.

The daily systems check list was set up to systematically check all water, oil, FC75, and SF_6 lines for leaks and proper flow. By checking auxiliary systems, in a standby mode, failures can be detected prior to operation. By checking the auxiliary systems daily, the entire system has become more reliable. Time lost due to faulty flow switches or leaks is virtually a thing of the past.

Gyrotron tanks are in open, easily accessible areas in the TMX-U pit. They are at times used as ladders and hand holds. Damage to equipment was not being noticed prior to operations. With the Quality Control system every detail of the tank is inspected daily. The remaining remote areas of the ECRH system are scrutinized as well.

There were several daily inspections that were down graded to weekly inspections. Failure rates of these items dictated this move. One such inspection is checking the outer Gyrotron window. The window is inspected for any signs of mode rings or foreign material. Dust and ash from burned gases will destroy a window extremely rapidly. By performing this inspection, several Gyrotron windows have been saved from potential damage. Another check is the inspection of the high-voltage capacitor bank. Any damage to bleeder resistors is noted and addressed on a weekly basis. There are 108 capacitors per bank. Each capacitor has two series bleeder resistors. Resistor failure results from age and dust particles that cause arcing. Down time due to these problems has been virtually eliminated. A copy of the check list is also on display.

Secondly, the system's equipment failure log was set up. This was accomplished on a Hewlett-Packard 9816 desk-top computer. All equipment failures are logged and can be sorted and reviewed. Any recurring problem can be dealt with by modifying the system to stop it from failing. The equipment failure log began showing failure trends and identified equipment that was being repaired with more than normal frequency. It became apparent that a complete re-design of the ECRH control system was needed. This project is now is progress. The ECRH system and TMX-U have benefited from the portions of the new control system already installed. Rebuilding of a high-voltage crowbar stack was undertaken due to continued failures. For the past eight months, there have been no major failures of the new crowbar stacks. The log also showed numerous failures of the current interrupt board. This board is very important because its job is to shut down the system if a fault occurs. If the board fails, system damage may occur. Re-design of the board was undertaken due to these failures. There have been no current interrupt board failures, to speak of, since the boards were re-designed.

Conclusion

Not every system is large or complex enough to dictate having a training guide or a strict quality control system. ECRH required that such programs and manuals be implemented. Quality control has increased system reliability by more then 30 percent. It helped train technicians in a faster, more organized manner. It helped to eliminate unnecessary cost due to down time. Due to the Quality Control system, ECRH is a more reliable, easier maintained, and more respected system.